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WEAK VECTOR COUPLING FROM NEUTRON β-DECAY AND POSSIBLE INDICATIONS FOR RIGHT-HANDED CURRENTS

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The results of the determination of weak interaction coupling constants (G'_V and G'_A) are presented, obtained from neutron lifetime and electron-spin asymmetry of neutron β-decay. Possible reasons for the discrepancy of G'_V-values are discussed.

The precise measurements of neutron β-decay give an opportunity for determination of vector and axial-vector constants of weak interaction. These constants are determined from experimental data for the neutron lifetime (τ_n) and the asymmetry of neutron β-decay (A_n). However, due to low accuracy in neutron experiment this method for a long time was not compatitive with the well known method for determination of G_V from superallowed $0^+ - 0^+$ nuclear transitions. Recently a substantial progress has been achieved in the accuracy of the neutron lifetime determination as well as in β-decay asymmetry [1-6]. Using the average value for the neutron lifetime $\tau_n = 887.0 \pm 1.6s$ and the average value for the electron-spin polarization asymmetry of β-decay $A_n^0 = -0.1126 \pm 0.0011$ one can obtain the results for vector and axial-vector constants ${}^nG'_V$ and ${}^nG'_A$:

$$ {}^nG'_V = G_V(1+\Delta_\beta)^{\frac{1}{2}} = (1.1584 \pm 0.0024)10^{-5}GeV^{-2}(\hbar c)^3, \tag{1}$$

$$ {}^nG'_A = G_A(1+\Delta_\beta)^{\frac{1}{2}} = (-1.4561 \pm 0.0014)10^{-5}GeV^{-2}(\hbar c)^3, \tag{2}$$

where Δ_β is the inner radiative correction to the process $n \to p + e^- + \tilde{\nu}_e$ in the standard electroweak theory.

The value of weak coupling constant as determined from β^+-decays in superallowed $0^+ - 0^+$ transitions has been presented in the several references, differing one from another by calculation of the nuclear structure corrections : ${}^{00}G'_V = (1.14809 \pm 0.00045)10^{-5}$ [7], ${}^{00}G'_V = (1.14939 \pm 0.00065)10^{-5}$ [8], ${}^{00}G'_V = (1.1510 \pm 0.0005)10^{-5}$ [9], ${}^{00}G'_V = (1.1516 \pm 0.0005)10^{-5}$ [9]. One can spot a systematic increase of G'_V with time. It seems, that the last value takes into account nuclear structure effects most carefully.

At last, vector coupling can be extracted from decays of strange particles using the G_μ-value and the unitarity of the Kobayashi-Maskawa matrix [10]: ${}^{un}G_V(1+\Delta_\beta)^{1/2} = G_\mu(1+\Delta_\beta-\Delta_\mu)^{1/2}(1-|V_{us}|^2-|V_{ub}|^2)^{1/2} = (1.1514 \pm 0.0015)10^{-5}$.

Besides this, a great interest has been aroused by the decay asymmetry and lifetime data of ^{19}Ne presented recently in ref.[11]. The positronic decay of ^{19}Ne is actually a proton's β^+ -decay in nuclei. The asymmetry and the lifetime measurements for ^{19}Ne ($A_{\rm Ne} = -0.03669 \pm 0.00083, (F\tau)_{\rm Ne} = 1717.6 \pm 3.7s$) give here: ${}^{\rm Ne}G'_V = (1.1478 \pm 0.0016)10^{-5}$, ${}^{\rm Ne}G'_A = (-1.0664 \pm 0.0013)10^{-5}$.

All the data described above are shown in fig.1. One can see a discrepancy between G'_V-value from neutron β-decay and the other G'_V-values. The largest contradiction is observed between G'_V-values from the neutron and ^{19}Ne (${}^nG'_V - {}^{\rm Ne}G'_V = 3.7\sigma$) . This contradiction survives at 2.1σ level even if the results on asymmetry [2] being the main source of this discrepancy are excluded.

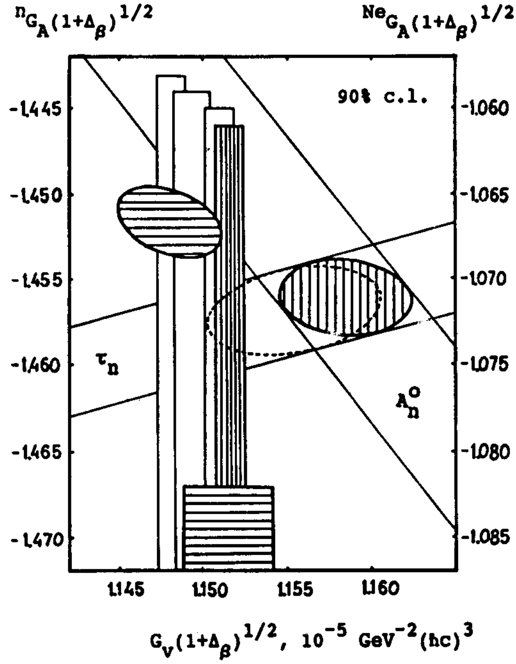

Fig 1.

Fig.1: Determination of the weak couplings from different experimental data (90 % c.l.): a) from the decay asymmetry A_n and the neutron lifetime τ_n -the right ellipse (the dotted-line ellipse is the same without the data from [2]), b) from the decay asymmetry of ^{19}Ne (A_{Ne}) and ^{19}Ne lifetime (τ_{Ne}) -the left ellipse, c) from the $F\tau$-data for $0^+ - 0^+$ transitions –high rectangles, d) from the decays of strange particles, G_μ and the unitarity of the Kobayashi-Maskawa matrix–the low rectangle.

It seems possible to follow the different directions for discussing of this contradiction: 1) it may result from the systematical lowering of the experimentally measured absolute value of decay asymmetry and/or the neutron lifetime, 2) it may be connected to the incomplete calculation of the radiative corrections, 3) it may be due to the presence of right-handed currents in the nucleon β-decay. The latter alternative can explain the largest discrepancy between the neutron and ^{19}Ne data. Further it will be shown that the choice between these options can be done by performing new, rather precise experiments: measurement the ratio $\frac{(A-B)}{(A+B)} = \lambda_{AB}$ (which implies simultaneous measuring the electron-spin (A) and the neutrino-spin polarization asymmetry (B), without exact determination of the neutron beam polarization) and measuring the B-value with the precise determination of this polarization.

Let us discuss, on a very preliminary basis, the third option, i.e. the existence of right-handed currents in the nucleon β-decay, which was considered in the different aspects in refs. [12,1,11]. Taking into account the right-handed currents [13] one has for electron-spin asymmetry :

$$A_n = -2\frac{\lambda_n^2(1-y^2) + \lambda_n(1-xy)}{(1+x^2) + 3\lambda_n^2(1+y^2)}, \tag{3}$$

and for the ratio of the lifetimes :

$$\frac{(F\tau)^{00}}{(F\tau)^{n}} = \frac{1}{2}(1 + 3\lambda_n^2 \frac{1+y^2}{1+x^2}) \equiv \frac{1}{2}(1 + 3\lambda_\tau^2), \tag{4}$$

$$(\lambda_n \equiv {}^nG'_A/{}^nG'_V).$$

This leads to the connection between the parameters δ and ζ of the model (in the quadratic approximation) :

$$A_n + 2\frac{\lambda_\tau^2 + \lambda_\tau}{1 + 3\lambda_\tau^2} = \frac{4(\lambda_\tau^2 + \lambda_\tau)}{1 + 3\lambda_\tau^2}\delta^2 + \frac{8\lambda_\tau^2}{1 + 3\lambda_\tau^2}\delta\zeta + \frac{4\lambda_\tau^2}{1 + 3\lambda_\tau^2}\zeta^2. \tag{5}$$

Here: $x = \delta - \zeta, y = \delta + \zeta, \delta$ is the ratio of the squared masses M_1^2 and M_2^2 (for the mass eigenstates $W_1 = W_L \cos\zeta - W_R sin\zeta$; $W_2 = W_R \cos\zeta + W_L \sin\zeta$), ζ is the mixing angle for W_L, W_R. The analogous equation can be written for ^{19}Ne. Adding and subtracting eqs.(5) for neutron and neon one can find the restrictions on the δ and ζ parameters. The allowed values of δ and ζ are shown in fig.2. The neutron data together with the most precise ^{19}Ne data, play the crusial role while the $0^+ - 0^+$ transitions are of the minor importance. It is worth mentioning, that by introducing the right-handed currents one can explain the different signs of deviations for ${}^nG'_V$ and ${}^{Ne}G'_V$ from ${}^{00}G'_V$. The region of restrictions in fig.2, marked by the dotted line corresponds to the case when the data for the asymmetry A_n of ref.[2] are excluded. One can see that even without these data the contradiction with the limits from μ^+-decay [14] is not removed. This discrepancy between the muon decay and the nucleon decay is a serious obstacle for explanation of the discussed above contradiction by the right-handed currents. Let us note that the imitation of W_R in the analysis may be simulated by the incorrect account of the radiative corrections.

The opportunity to distinguish between these possibilities comes from the analysis of the expressions for $F\tau$ and the decay asymmetry. With the contribution of the right-handed currents and radiative corrections taken into account but for the mixing angle $\zeta = 0$ one has (the right hand of the eqs. given below correspond to the leading order in $\delta = M_L^2/M_R^2$):

$$\frac{(F\tau)^{00}}{(F\tau)^{n}} = \frac{1}{2}(1 + 3\lambda_n^2 \frac{1+y^2}{1+x^2})\frac{1+\Delta_\beta^n}{1+\Delta_\beta^{00}} \approx \frac{1}{2}(1 + 3\lambda_n^2)\frac{1+\Delta_\beta^n}{1+\Delta_\beta^{00}}, \tag{6}$$

$$A_0 = -2\frac{\lambda_n^2(1-y^2) + \lambda_n(1-xy)}{(1+x^2) + 3\lambda_n^2(1+y^2)} \approx -2(1-2\delta^2)\frac{\lambda_n^2 + \lambda_n}{1+3\lambda_n^2}, \tag{7}$$

$$B_0 = 2\frac{\lambda_n^2(1-y^2) - \lambda_n(1-xy)}{(1+x^2) + 3\lambda_n^2(1+y^2)} \approx 2(1-2\delta^2)\frac{\lambda_n^2 - \lambda_n}{1+3\lambda_n^2}, \tag{8}$$

$$\frac{A_0 - B_0}{A_0 + B_0} = \lambda_n \frac{1-y^2}{1-xy} \approx \lambda_n. \tag{9}$$

Here Δ_β^n and Δ_β^{00} are the uncalculated radiative corrections, A_0 and B_0—experimental values of electron-spin and neutrino-spin asymmetry, corrected by extracting of the recoil and weak magnetism effects. The radiative corrections are omitted in eqs. (7),(8) and (9) since they are negligible in comparison with the experimental accuracy. Since the quantity B_0 is the measured value of the neutrino-spin asymmetry, in the absense of the right-handed current it equals to $2(\lambda_n^2 - \lambda_n)/(1+3\lambda_n^2)$. When the right-handed currents are present we can construct the quantity $\lambda_{AB} = \frac{A_0-B_0}{A_0+B_0}$, which coincide with λ_n if $\zeta = 0$. Then the value of $B_{AB} \equiv 2(\lambda_{AB}^2 - \lambda_{AB})/(1+3\lambda_{AB}^2)$ differs from B_0 only due to the existence of the right-handed currents:

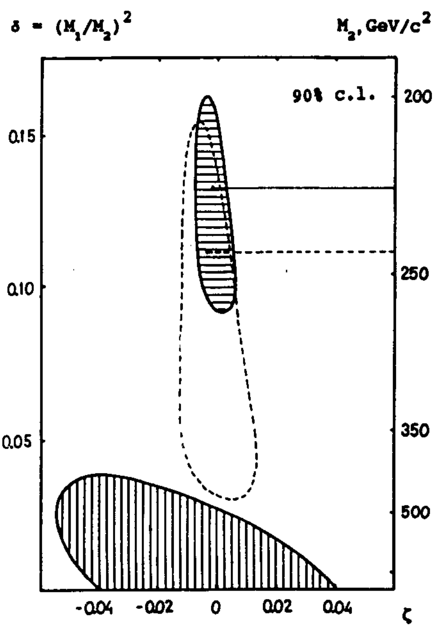

Fig.2.

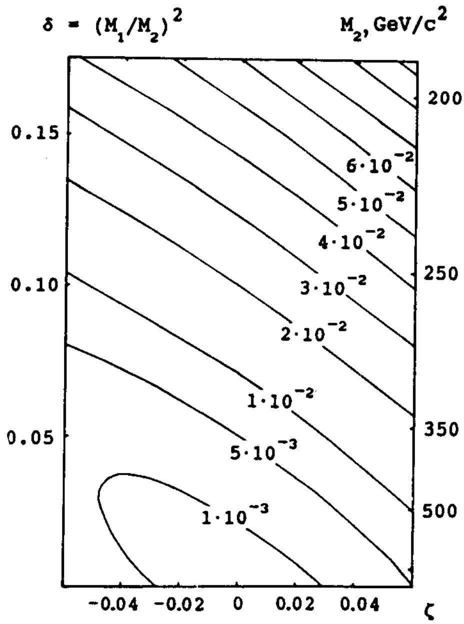

Fig.3.

Fig.2: The region of restrictions for the left-right model parameters δ and ζ from different experimental data (90 % c.l.): a) from β^--decay of neutron and β^+-decay of ^{19}Ne - horizontal shaded region, the most probable value $M_{W_R} = 220\ GeV/c^2$ (the region shown by the dotted line- the same without data from [2]) ,the most probable value $M_{W_R} = 240\ GeV/c^2$, b) from the μ^+-decay data - the vertical shaded region, $M_{W_R} > 432\ GeV/c^2$

Fig.3: The correlation between δ and ζ for different values of the deviation parameter $(\frac{B_{AB}}{B_0} - 1)$.

$$\frac{B_{AB}}{B_0} - 1 = 2\delta^2 + 4\frac{3\lambda_{AB}^2 - 1}{3\lambda_{AB}^2 + 1}\delta\zeta + 2\frac{3\lambda_{AB}^2 - 1}{3\lambda_{AB}^2 + 1}\zeta^2. \tag{10}$$

The graphical relation between the parameters δ and ζ from eq.(10) is presented on the fig.3 for different values of the deviation parameter $(\frac{B_{AB}}{B_0} - 1)$. The use of the quantities A_0 and B_0 allows to avoid the exact account of the radiative corrections. How one can see from the fig.3 to confirm (or to reject) the presence of the W_R one should measure B with the accuracy of about 0,3-0,5 % . This seems possible when using the special method for measuring the neutron beam polarization [15,16]. The use of quantities A and λ_{AB} is less attractive since it needs the high precision of measurements. Besides, the role of radiative corrections for A may have an appreciable influence, whereas for quantities B and (A-B)/(A+B) this influence is much less (since $A \approx 0,1B$).

Thus the correct analysis for the right-handed currents needs the comparison of the results, obtained from measurement of B and (A-B)/(A+B), instead of A and $(F\tau)^{00}/(F\tau)^n$ as it has been made before. To complete the analysis one can evaluate the uncalculated radiative corrections through measurement of the quantaties $(F\tau)^{00}$, $(F\tau)^n$ and λ_{AB}:

$$\Delta_\beta^n - \Delta_\beta^{00} = \frac{(F\tau)^{00}}{(F\tau)^n}\frac{2}{1 + 3\lambda_{AB}^2} - 1. \tag{11}$$

Thus at the present time the most important goal is to carry out the measurement of the ratio $\lambda_{AB} = \frac{A_0-B_0}{A_0+B_0}$ and the measurement of B with the improved accuracy . This will allow to make a choice between the three discussed possibilities of the source of ${}^{n}G'_V$ and ${}^{00}G'_V$, ${}^{Ne}G'_V$ discrepancy. For example, the option of the right-handed currents is excluded if $B_0 = B_{AB}$, while the possibility of additional radiative corrections is excluded if $\lambda_{AB} = \lambda_r$. By means of the more complicated analysis one can get indication on the possible systematic errors or accident deviations in the former experiments.

To conclude, we can notice, that if $(\frac{B_{AB}}{B_0} - 1) \approx 3 \cdot 10^{-2}$ (so that the region of mass values for W_R at fig.2 is confirmed), then the contradiction with the μ-decay restrictions can be avoided by the assumption that the right-handed neutrinos have Majorana masses and that the following relations are valid:

$$m_{\nu_\mu^R} > m_\mu - m_e - m_{\nu_e^R},$$

$$m_{\nu_e^R} < m_n - m_p - m_e.$$

The decay through the W_R is then forbidden for the muon while it is possible for the neutron.

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